AVIAN LINE-TRANSECT METHODS

Section 6.3.2, US ARMY CORPS OF ENGINEERS WILDLIFE RESOURCES MANAGEMENT MANUAL

by

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This report on avian line-transect methods is provided as Section 6.3.2 of the US Army Corps of Engineers Wildlife Resources Management Manual. The report is designed to assist the District or project biologist in the application of line-transect methods to estimate the density and diversity of bird populations for planning, management, and research purposes.

The basic line-transect survey involves walking a predetermined straight path and recording detections of birds along both sides of the line. The method is best suited to fairly large areas with homogeneous vegetation and gentle terrain, and can be used at any time of year. The report provides guidelines concerning transect establishment, sample size, survey timing and procedures, and interpretation of results, including an explanation and comparison of fixed-width transects, Emlen's method, and a modified Emlen's method.

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PREFACE

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1

NOTE TO READER

This report is designated as Section 6.3.2 in Chapter 6 -- CENSUS AND SAMPLING TECHNIQUES, Part 6.3 -- BIRD SURVEY/CENSUS TECHNIQUES, of the US ARMY CORPS OF ENGINEERS WILDLIFE RESOURCES MANAGEMENT MANUAL. Each section of the manual is published as a separate Technical Report but is designed for use as a unit of the manual. For best retrieval, this report should be filed according to section number within Chapter 6.

AVIAN LINE-TRANSECT METHODS

Section 6.3.2, US ARMY CORPS OF ENGINEERS
WILDLIFE RESOURCES MANAGEMENT MANUAL

Line-transect sampling methods are widely used to estimate the density of bird populations. Although there are many variations of the technique, the basic line-transect survey involves walking a predetermined straight path (the transect) and recording detections of birds along both sides of the transect line. Variations of the transect method differ in their underlying assumptions, statistical properties, and in the way the data are manipulated to estimate bird density. In this section, 4 approaches to line-transect sampling are discussed: (1) fixed-width or belt transects, (2) Emlen's variable-width transects, (3) a modified Emlen's method, and (4) methods involving statistical detection functions. Detailed reviews of line-transect techniques are given by Seber (1973), Eberhardt (1978), and Burnham et al. (1980). Robinette et al. (1974) present field tests of several older methods.

The line-transect method is best suited to relatively large, homogeneous areas where vegetation and topography allow the establishment of one or more straight, obstacle-free transect lines. The approach is not limited to any particular species, region, or habitat type; it has been used successfully to

count songbirds in forests, grasslands, and brush; waterfowl and other game-birds from automobiles and aircraft; and seabirds from ships. It can be applied to a single species or to an avian community (e.g., forest songbirds), although densities are usually estimated separately for each species. Furthermore, transect methods can be used at any time of year, whereas many other methods are limited to the breeding season.

BACKGROUND

In the simplest form of a line-transect survey, a single transect is established within an area with known boundaries to estimate the density of a bird population having members scattered throughout the area. An observer slowly walks the length of the transect searching for birds. For each bird seen, the observer measures the perpendicular distance (x) from the transect line to the point where the bird was first detected (Fig. 1). Alternatively, both the sighting distance (r) from the observer to the bird when it was detected and the sighting angle (θ) between the transect line and the line of sight can be measured. Most of the newer line-transect estimators are based only on perpendicular distances. Sighting distances and sighting angles can be used to calculate perpendicular distances when the latter are more difficult to measure, and a few older methods use sighting distances and angles directly in estimating animal density.

An observer moving along the transect is likely to see all birds located on or very near the line. However, the probability of detecting a bird diminishes as distance from the transect increases. Some line-transect estimators require that the observer detect all birds that are within a certain distance of the transect line; beyond this distance, some birds can be missed. Other estimators incorporate detection functions that describe mathematically the decline in detectability at increasing distance; the density of birds can be calculated only after the detection function is determined.

ASSUMPTIONS

Several assumptions are common to most line-transect methods. These include:

(1) Transect lines are located at random with respect to the birds being counted.

(2) Birds located directly on the transect are never missed.

(3) Birds do not move before they are detected.

(4) Each bird is counted only once.

(5) Sightings are independent events.

(6) Perpendicular distances (or sighting distances and angles) are measured without error.

In practice, none of these assumptions is ever totally realized. For example, canopy-using birds may be missed even when they are directly over the transect line; birds on the ground may walk away from the line before they flush and
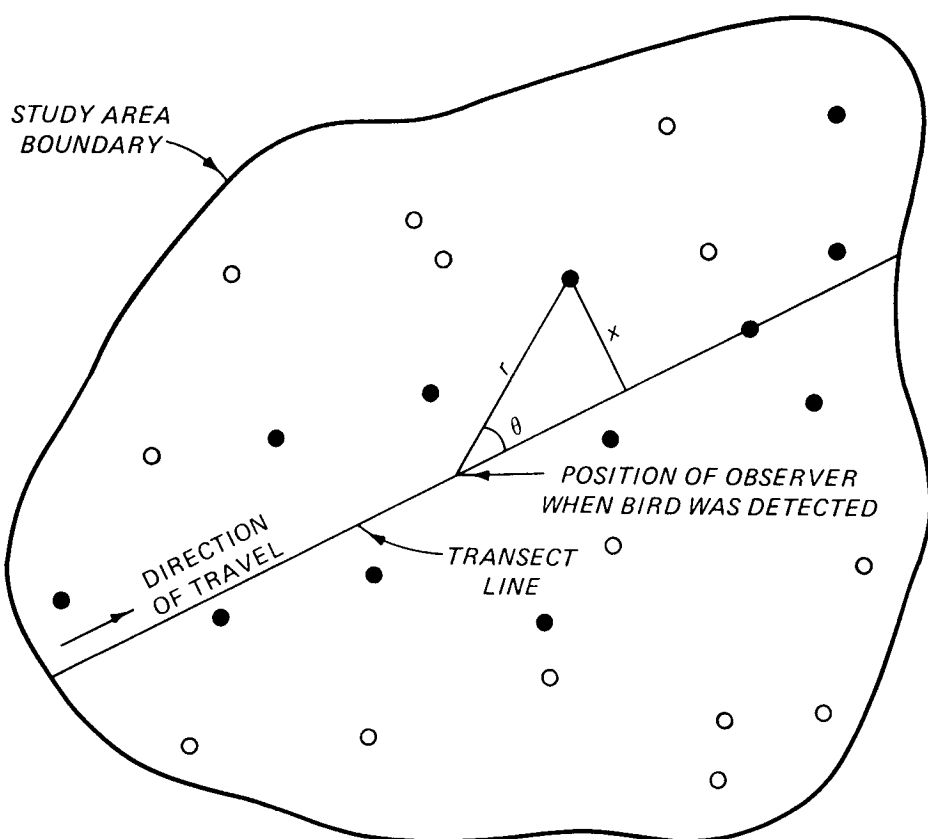
Figure 1. General representation of line-transect sampling of a bird population. An observer walking along the transect line detects some birds (solid circles) and fails to detect others (hollow circles). For each bird observed, either the perpendicular distance (x), or both the sighting distance (r) and the sighting angle (θ) are measured. Most line-transect methods use the distribution of right-angle distances to estimate population density

5

are seen; birds that flush parallel to the transect line may be encountered again; and the flush of one bird may startle other birds that otherwise would not have been detected. An investigator must recognize the limitations of the technique and apply it with care. For species that normally form groups (e.g., quail coveys, grouse broods), it may be best to treat each group as a single entity (measuring distances to the group center) and adjust the density estimate by the average group size.

STUDY DESIGN

Transect Establishment

Transect lines can be located throughout the project area in a random, systematic, or stratified pattern. It is not necessary that the arrangement of transects be completely random, only that they be random with respect to the distribution of birds being counted. In practice, a systematic arrangement of lines is more easily established and permits more efficient use of the observer's time. One such arrangement consists of evenly spaced parallel transects (Fig. 2), with the first line located a random distance from the edge of the study area. In a design of this type the total transect length equals the sum of the lengths of the individual transect lines. Depending upon the size of the study area, habitat type, and conspicuousness of the species being counted, the distance between transects may range from 50 m (165 ft) to more than 1 km (0.6 mi). Transects should not cross or approach each other so closely that individual birds might be counted twice. The best way to determine minimum transect spacing is to do some preliminary sampling in the intended study area to find the maximum distances at which various species can be seen and heard. The minimum transect spacing must be at least twice the maximum detection distance for the most easily detectable bird species of interest.

If two or more dissimilar habitats (e.g., forest, shrubland, grassland) are sampled, the placement of transects should be stratified by habitat type. That is, separate transects should be established in each habitat, and data should be collected and analyzed separately. If stratification results in areas that are too small to provide adequate samples, an alternate sampling technique, such as variable circular plots, may be more appropriate. Ramsey and Scott (1981) developed a procedure, presented later in this report, to estimate bird density from line-transect surveys in heterogeneous study areas.
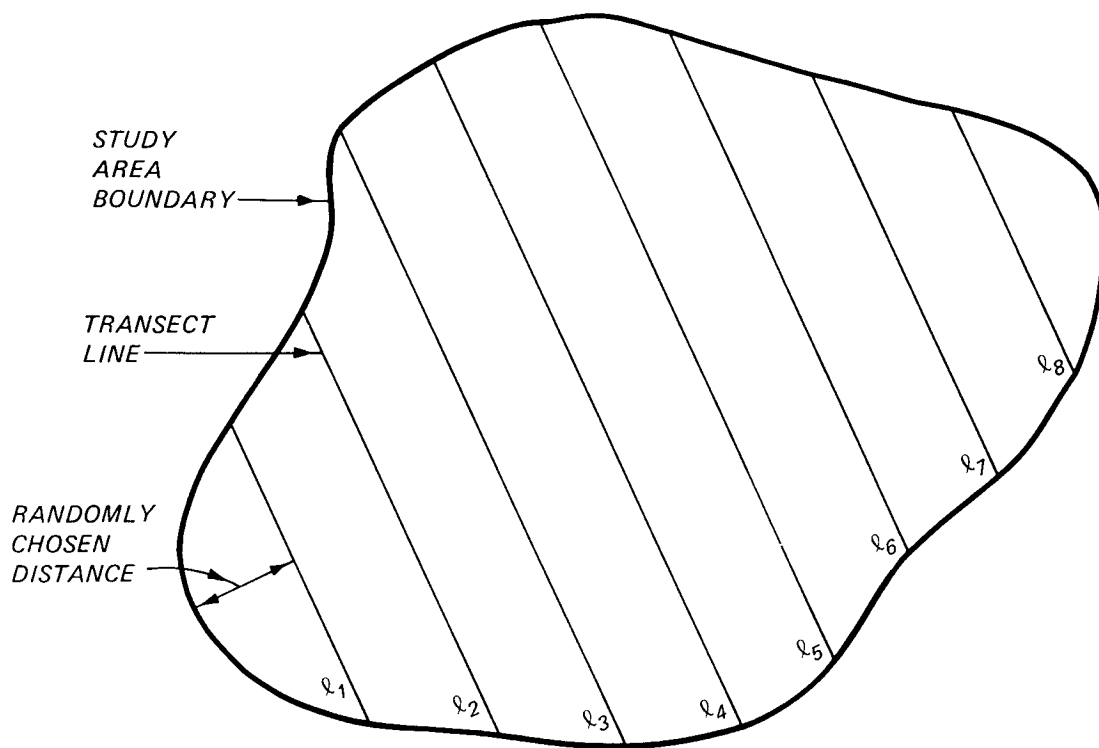
Figure 2. A systematic arrangement of evenly spaced transect lines
starting a random distance from the study area boundary.
The total transect length (L) is the sum of the lengths
($\ell_1 + \ell_2 + \ldots + \ell_n$) of the individual lines

Transects should be fairly free of entangling vegetation and other obstacles that might distract the observer or cause him to deviate from the line. Transects that will be used repeatedly to study seasonal or annual changes in bird populations should be permanently marked with numbered stakes at regular intervals. In open habitats, stakes should be short to reduce their attractiveness to perching birds.

Sample Size

At least 40 observations of a species are needed to calculate a reliable estimate of its density (Burnham et al. 1980). Therefore, in designing a line-transect survey, an investigator should establish a total length of transects (or plan for enough replicate samples) that will allow this number to be reached or exceeded.

Timing

The daily and seasonal timing of line-transect surveys depends on the investigator's goals. Sampling is generally more efficient when the target species are most active. Breeding birds are usually sampled between 1/2 hour before and 3 to 4 hours after sunrise. Winter birds are best counted later in the morning after the temperature has risen from its nighttime low. Sampling should be done on days when rain, wind, or cold temperatures do not hamper the observer or reduce the mobility or detectability of the birds. To ensure that only residents are counted, breeding birds should be sampled after migrants have passed through the area. Annual bird surveys should be done at approximately the same time each year, so that samples reflect population size at the same point in the birds' annual cycle. National Audubon Society chapters or other bird clubs are excellent sources of information on the timing of migrations and breeding activities of local bird species.

Data Collection

Line-transect methods assume that the perpendicular distance from the transect to the bird is measured without error. Some authorities recommend that distances be measured accurately with a tape; however, most field workers estimate distances by pacing or with an optical range finder. Pacing should be used only after pace length has been measured under field conditions. Distances should be estimated as accurately as possible and should not be rounded into categories (e.g., 0 to 5 m, 5 to 10 m, ...).

Standardized field data forms are needed to ensure that all required information is recorded. Figure 3 shows a sample form that can be photocopied for field use. If the data are to be analyzed by computer, the field form should be designed to allow direct input of the information. In that case, the format of the data form should match the input requirements of the software to be used. Additional guidelines for the collection of line-transect field data are given by Mikol (1980).

TRANSECT SURVEY FORM

TRANSECT NUMBER:_____

OBSERVER:_____

SURVEY NUMBER:_____

DATE:_____

VEGETATION:_____

START TIME:_____

WEATHER:_____

FINISH TIME:_____

SIGHTING NUMBER	SPECIES	NO. OF BIRDS	RIGHT-ANGLE DISTANCE	SIGHTING DISTANCE	SIGHTING ANGLE	COMMENTS

Figure 3. Sample field data form for line-transect surveys

In a fixed-width transect survey, transect width is established in advance of sampling at some distance small enough to allow all birds within the transect to be detected and counted. Fixed-width or belt transects offer practical advantages over more sophisticated line-transect methods. In particular, they are easy to perform. The observer simply decides whether a bird is inside or outside the predetermined transect width; measurements of perpendicular distances need not be taken except for borderline cases. Furthermore, the calculation of bird density is straightforward. A belt transect is nothing more than an elongated sampling plot with a known length and width. Therefore, the number of birds on a plot, or a series of plots, can be readily expanded into a population estimate for the entire study area.

The greatest disadvantage of fixed-width transects is the assumption that all birds within the transect are detected. The investigator must decide whether that assumption is reasonable for the bird species and field conditions under which the count will be taken. If the data indicate that birds near the transect boundary are being overlooked, then Emlen's method (presented later in this report) or the correction factor described by Anderson and Pospahala (1970) should be used.

Procedure

Procedures applicable to fixed-width transect sampling of bird populations were presented earlier under the heading Study Design. In addition, an appropriate transect width must be chosen. Because the reliability of population estimates depends on the number of birds counted, transects should be wide enough to permit an adequate number of sightings, but narrow enough that individuals at the edge of the strip are not overlooked. The appropriate transect width will depend on the species being counted, terrain, and density of vegetation and should be determined by preliminary sampling in the intended study area. A distance of 5 to 10 m (15 to 30 ft) on each side of the transect line may be adequate to count nests in seabird colonies, whereas 25 to 50 m (80 to 165 ft) may be required to count songbirds in a forest and 100 m (330 ft) or more may be needed to count large birds (e.g., herons) in open habitats. Different transect widths may be used for different bird species, even in the same survey.

Analysis

If transects are representative of conditions throughout the study area, the density of birds within the transect(s) is the same as the density of birds in the whole area. Density is calculated as

$$D = n/2Lw \qquad (1)$$

where:

D = density

n = number of birds counted within the transect

L = length of the transect

w = 1/2 the total transect width (birds are counted within distance w on each side of the center line)

Note that L and w must be in the same units. Densities for each species are usually converted to some common unit, such as birds/100 ha.

Each transect is usually surveyed repeatedly (perhaps 8 to 10 times) over a period of days or weeks, allowing calculation of the average density, $\bar{D}$, of each species and its standard error. A 95% confidence interval around the mean density is estimated by

$$95\% \text{ confidence interval} = \bar{D} \pm 1.96s \qquad (2)$$

where s = standard error of the mean .

The standard error and 95% confidence interval around $\bar{D}$ can also be calculated for a series of equal-length transects run only once by treating each transect as a replicate. However, this will result in a wide confidence interval. The use of fixed-width transects to estimate bird density is illustrated in Example 1.

EMLEN'S METHOD

Emlen (1971, 1977) developed a line-transect method in which the effective strip width is determined subjectively by examining the data after sampling. This technique is perhaps the most commonly used transect method for population studies of North American birds. Emlen's method assumes that, within a certain threshold distance from the transect line, the observer detects all birds that are present. Beyond that distance, the ability of the

Example 1

Calculation of Bird Density from Fixed-Width Transects

Fixed-width transects were used to estimate the density of Steller's jays (*Cyanocitta stelleri*) in a 200-ha study area in Colorado. Six parallel transect lines each 200 m long (L = 1200 m) were established by starting at random points along the only access road through the study area; adjacent transects were at least 150 m apart. Preliminary sampling had indicated that Steller's jays were readily detectable up to 40 m away; therefore, transect width was fixed at 40 m on each side of the line (w = 40 m). Birds beyond that distance were ignored. All transects were sampled 10 times during a 30-day period.

On the first day of sampling, 18 birds were counted. According to equation 1, the density of jays is estimated as follows:

$$D = 18/(2 \times 1200 \times 40) = 0.000188 \text{ bird/m}^2$$

This result should be converted to a more convenient unit, such as birds per 100 hectares (1 square kilometer). There are 1 million square meters in 100 hectares. Converting the previous answer gives

$$D = 0.000188 \times 1,000,000 = 188 \text{ birds/100 ha}$$

Results for the 10 days of sampling are given below.

Day	Number of Birds Counted	Birds per 100 Hectares
1	18	188
2	23	240
3	9	94
4	20	208
5	15	156
6	27	281
7	13	135
8	16	167
9	20	208
10	13	135

Mean = 181 birds/100 ha

(Continued)

12

Example 1 (Concluded)

The best single estimate of bird density in the study area is the mean density over the whole sampling period, or 181 birds/100 ha. The standard error of this estimate is calculated by the following formula, given in any basic statistics book:

$$s = \sqrt{\frac{\Sigma\ (x - \bar{x})^2/(n - 1)}{n}}$$

where:

s = standard error

x = density on a given day

$\bar{x}$ = mean density

n = number of days

For the above example, the standard error = 17.5.

Therefore, by equation 2, a 95% confidence interval around the mean is calculated as follows:

95% confidence interval = 181 ± (1.96 × 17.5)

= 181 ± 34.3

Therefore, the lower limit on the confidence interval is

Lower limit = 181 − 34.3 = 147 birds/100 ha

and the upper limit is

Upper limit = 181 + 34.3 = 215 birds/100 ha

13

observer to detect a bird declines. This effective detection distance is different for each species, habitat, and observer.

Procedure/Analysis

The detection distance for Emlen's method is estimated by creating a histogram of the observed density of a species at various distances from the transect line (Fig. 4). Distance categories used in the histogram should be fairly small (3 to 10 m [10 to 30 ft]) for unobtrusive birds in dense habitats; they should be larger (10 to 25 m [30 to 80 ft]) for noisy birds or those occupying more open habitats.

If birds were uniformly or randomly distributed within the habitat, one would expect the density of birds in each distance category to be fairly constant. Instead, the histogram declines because birds farther from the line remain undetected. Therefore, the effective strip width is determined by the distance at which the histogram drops off (Fig. 4). The density of birds is then calculated as before by using equation 1. For Emlen's method, n = number of birds observed within distance w , and w = effective detection distance . For the data plotted in Fig. 4, n = 38 birds, w = 25 m, and L = 5000 m. Therefore, D = 152 birds/100 ha. A 95% confidence interval can be calculated by the same procedure as for fixed-width transects.

On any study area, some species are so uncommon that too few individuals are counted from transects to allow the estimation of an effective detection distance. In such cases, Emlen (1971) suggested using the effective detection distance of an equally detectable but more common species to estimate the density of the rarer species. For example, song sparrows (*Melospiza melodia*) and field sparrows (*Spizella pusilla*) may exist in the same study area and might be considered equally detectable. If 60 song sparrows and only 10 field sparrows are counted, the effective detection distance determined for song sparrows might be used to estimate the density of field sparrows.

Counting Breeding Birds

During the nonbreeding season, detection-distance histograms and population estimates should be developed using all available sight and sound detections of each species. For territorial songbirds during the breeding season, however, Emlen (1977) recommended that population estimates be derived solely
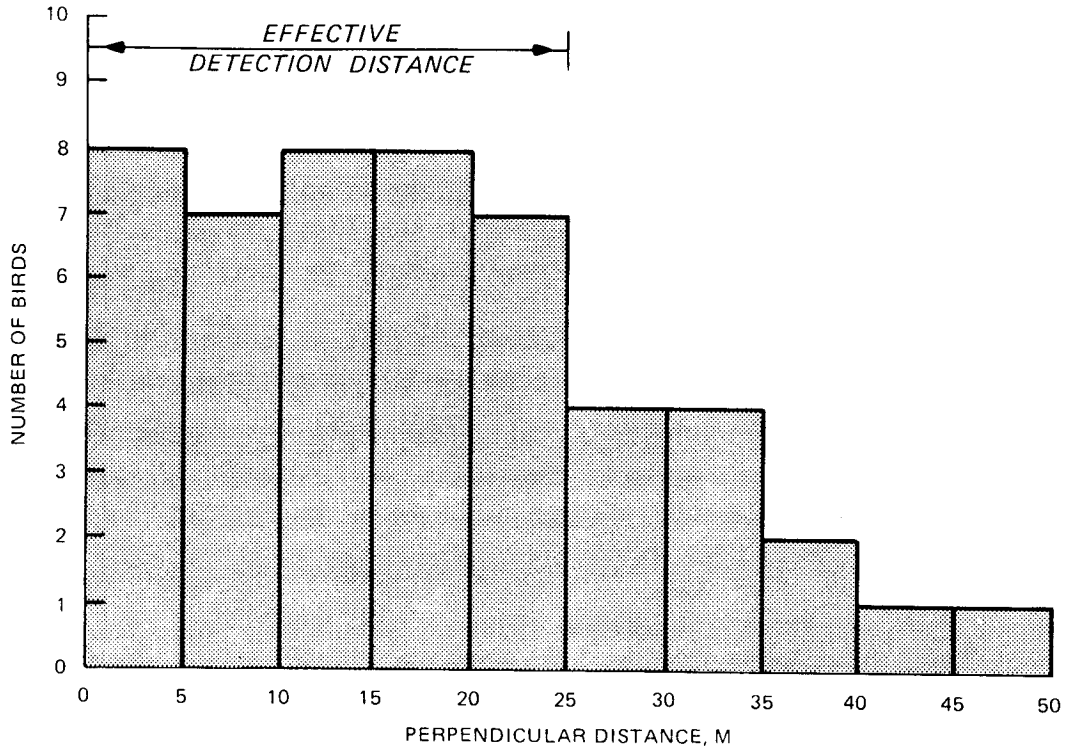
14

Figure 4. Hypothetical distribution of observations of tufted
titmice (*Parus bicolor*) along a 5000-m (16,400-ft)
transect line in deciduous forest habitat

from counts of singing males; estimates should then be adjusted for undetected
males and nonsinging females.

Territorial males may go undetected because they might not sing during
the brief time that an observer walking a transect line is within hearing
range. When songs can be heard up to 60 m (200 ft) away and the observer
moves at 1.2 km/hr (0.75 mi/hr), the observer is exposed to each bird for only
about 6 minutes. If independent observations show that males of that species
emit songs during only 50% of a sample of 6-minute periods, the count of sing-
ing males should be multiplied by 2 to adjust for undetected males (Emlen
1977). The number of uncounted females can be estimated if the sex ratio is
known. For monogamous songbirds, the total population size is often deter-
mined by multiplying the estimated number of males by 2.

Limitations

The major disadvantage of Emlen's method is the subjectivity with which effective detection distances are estimated. Sample size will be small for most species, resulting in a highly variable histogram without a clear inflection. Furthermore, Emlen's technique suffers from the familiar shortcoming of transect methods that birds on or near the transect line can be overlooked. Emlen (1971) suggested that transect counts could be calibrated by running transects in an area where bird densities have been determined by a second, presumably more reliable, census method such as territory mapping. However, this is a time-consuming procedure that is probably unnecessary for most applications.

MODIFIED EMLEN'S METHOD

Ramsey and Scott (1981) modified Emlen's method to permit the use of all detections of a species in estimating density. This allows fuller use of a data set than does Emlen's method, which discards observations beyond the effective detection distance. Ramsey and Scott's improvements can also be applied to variable circular plot surveys (refer to Section 6.3.3 of this manual).

Procedure/Analysis

Ramsey and Scott (1981) developed the concept of the effective area surveyed (E) as a measure of the observer's effort in counting birds. This area is larger than the area of the strip within which all birds present are presumably detected. The effective area surveyed is calculated as follows:

$$E = (n/m) \times A \tag{3}$$

where:

E = effective area surveyed

n = total number of birds detected

m = number of birds detected within A

A = area of the strip within which all birds present are detected

Ramsey and Scott (1981) offer two ways to estimate E for a species by using either grouped or ungrouped measurements of distance. For grouped data, their technique is equivalent to Emlen's (1971) in that a histogram of bird density versus distance (Fig. 4) is used to determine an effective detection

16

distance. Therefore, the area of the strip within which all birds are detected, A , is simply calculated by multiplying the transect length, L , by twice the effective detection distance, w . The effective area surveyed, E , is then calculated by equation 3.

To avoid problems that may be caused by the arbitrary selection of the intervals for grouping distance measurements, Ramsey and Scott (1981) suggested a graphical analysis of ungrouped data to determine E directly, without first estimating an effective detection distance. They developed a "cumulative-detection curve" showing the number of birds detected with increasing area (i.e., as a result of increasing transect width). The effective area surveyed, E , is determined by identifying the zone of greatest slope in the curve, extrapolating that slope upward to the line representing the total number of detections and downward to the horizontal axis, and reading the projection of this line onto the horizontal axis (Fig. 5).
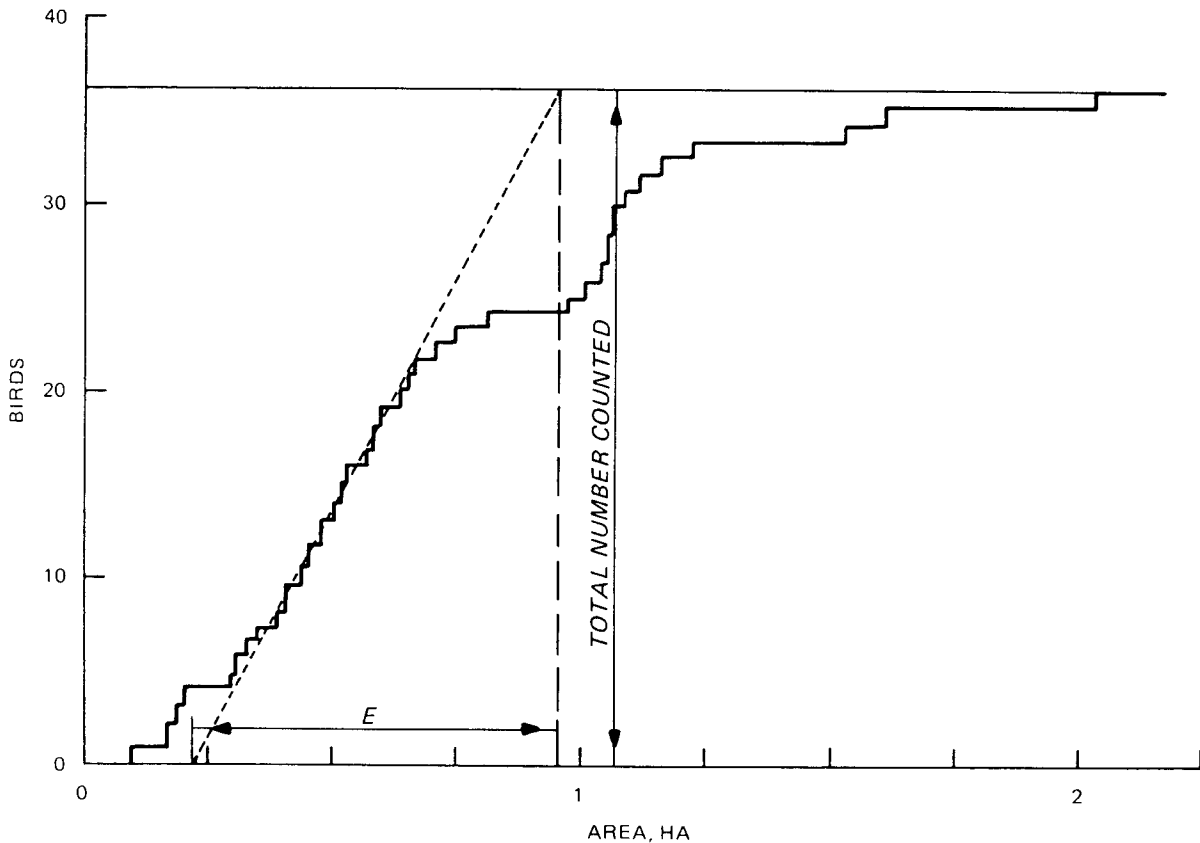

Figure 5.   Hypothetical cumulative-detection curve used to estimate the effective area surveyed (E). In this example, E is approximately 0.75 ha (1.85 acre). (Redrawn from Ramsey and Scott 1981)

17

Once E has been determined for a species, bird density is simply cal-
culated as follows:

$$D = n/E \qquad (4)$$

where:

D = bird density

n = total number of birds detected

E = effective area surveyed

Heterogeneous Habitats

Often it is desirable to estimate the density of a bird population occu-
pying an area containing more than one cover type or stand age, within which
bird detectability may differ. Ramsey and Scott (1981) proposed a method that
begins by dividing the area into subunits based on expected detectability.
These subunits may be delineated from a cover type or stand map, with patches
having similar vegetation structure combined into one detectability class.
For example, areas containing dense shrub cover might be lumped into one
subunit regardless of differences in plant species composition.

Data from transects or segments of transects falling within a subunit are
then analyzed separately to determine the effective area surveyed and number
of birds counted within the subunit. The average density across all subunits
is calculated as follows:

$$D = (\sum_{j} n_j A_j / E_j) / (\sum_{j} A_j) \qquad (5)$$

where:

n_j = total number of birds detected in subunit j

A_j = area of subunit j

E_j = area effectively surveyed within subunit j

The variance of D is estimated as follows:

$$\text{Variance} = [\sum_{j} n_j (A_j / E_j)^2] / (\sum_{j} A_j)^2 \qquad (6)$$

A 95% confidence interval around the mean density is calculated as follows:

$$95\% \text{ confidence interval} = D \pm 1.96 \sqrt{\text{variance}} \qquad (7)$$

18

Example 2 illustrates the use of Ramsey and Scott's (1981) method to estimate bird density in a forest comprised of different stand ages.

DETECTION-FUNCTION METHODS

The decline in detectability of a bird at increasing distance from the transect line can be defined mathematically by a "detection function." The detection function $g(x)$ is the probability of observing a bird that is located at perpendicular distance x from the transect line (Burnham et al. 1980). Burnham et al. (1980) described a variety of sophisticated parametric and nonparametric techniques that use detection functions for estimating animal density from line-transect data. The statistical procedures are beyond the scope of this manual and are too laborious for hand calculation. Fortunately, Laake et al. (1979) have developed a Fortran program for mainframe computers, called TRANSECT, which is available at cost from SHARE Program Library Agency, P.O. Box 12076, Research Triangle Park, NC 27709. The program consists of a main program and 57 subroutines, plus examples used in Burnham et al. (1980). Gates (1980) has written another program called LINE-TRAN, which uses a variety of methods to estimate animal density from line-transect surveys.

CAUTIONS AND LIMITATIONS

Line-transect methods are best suited for use in large study areas with fairly uniform vegetation and level terrain, whereas plot methods may be more efficient in small areas or rugged terrain. Fixed-width transects are easy to sample, but transect width must be chosen with care to avoid overlooking birds located near the transect boundaries. Emlen's (1971) variable-width transect method alleviates this problem, but the determination of transect width is highly subjective. Ramsey and Scott's (1981) modifications of Emlen's technique reduce this subjectivity and allow the use of all detections in estimating bird density. All transect methods are based on assumptions that may or may not reflect conditions in an actual field application.

Example 2

Calculating Bird Density in a Heterogeneous Study Area

A 1500-ha forested tract consists of 890 ha of pole-sized timber and 610 ha of saw timber. Because bird detectability may differ in the two stand types, Ramsey and Scott's (1981) method was chosen to estimate bird density in the entire tract. Line-transect surveys were accomplished on 25 randomly located 1-km transects, 14.3 km of which fell in pole stands and 10.7 of which were in saw timber stands. Each transect was sampled only once.

To estimate the density of red-eyed vireos (*Vireo olivaceus*), cumulative detection curves were used to determine effective areas sampled in pole timber and saw timber separately. The basic information needed to calculate the density estimate was as follows (distances and areas have been expressed in kilometers and square kilometers, respectively):

	Pole Timber	Saw Timber
Area of the subunit (A)	$8.9 \ km^2$	$6.1 \ km^2$
Effective area surveyed (E)	$1.72 \ km^2$	$1.93 \ km^2$
Number of birds counted (n)	97 birds	64 birds

Therefore, by equation 5, the density of vireos is calculated as follows:

$$D = \frac{\dfrac{97 \times 8.9}{1.72} + \dfrac{64 \times 6.1}{1.93}}{8.9 + 6.1}$$

$$D = (501.9 + 202.3)/15.0 = 46.9 \ birds/km^2$$

The variance is calculated by equation 6 as follows:

$$Variance = \frac{97 \ (8.9/1.72)^2 + 64 \ (6.1/1.93)^2}{(8.9 + 6.1)^2}$$

$$Variance = (2597.1 + 639.3)/225.0 = 14.38$$

Therefore, by equation 7, the 95% confidence interval is:

$$95\% \ confidence \ interval = 46.9 \pm 1.96 \ \sqrt{14.38}$$

$$= 46.9 \pm 7.4 \ birds/km^2$$

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